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Description

Process and apparatus for reducing the content of NO_x and N₂O in gases

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The present invention relates to a process for reducing the content of nitrogen oxides in gases, in particular in process gases and offgases, and also an apparatus suitable for carrying out this process.

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Many processes, e.g. combustion processes or in the industrial preparation of nitric acid, produce an off-gas laden with nitrogen monoxide NO, nitrogen dioxide NO₂ (together referred to as NO_x) and nitrous oxide N₂O.

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While NO and NO₂ have long been known as compounds having ecotoxic relevance (acid rain, smog formation) and limit values for maximum permissible emissions of these have been set worldwide, nitrous oxide has increasingly moved into the focus of environmental

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protection in recent years, since it contributes to a not inconsiderable extent to the degradation of stratospheric ozone and to the greenhouse effect. For reasons of environmental protection, there is an urgent

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need for technical solutions which enable nitrous oxide emissions to be eliminated together with the NO_x emissions.

Numerous possible ways of separately removing firstly N₂O and secondly [lacuna] are known.

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In the case of NO_x reduction, particular mention may be made of the selective catalytic reduction (SCR) of NO_x by means of ammonia in the presence of vanadium-containing TiO₂ catalysts (cf., for example, G. Ertl,

35 H. Knözinger J. Weitkamp: Handbook of Heterogeneous Catalysis, Vol. 4, pages 1633-1668, VCH Weinheim (1997)). This can, depending on the catalyst, proceed at temperatures of from about 150°C to about 450°C and makes it possible to decrease the concentration of NO_x

by more than 90%. It is the most widely utilized variant of the removal of NO_x from offgases from industrial processes.

5 Processes for the reduction of NO_x which are based on zeolite catalysts and proceed using a variety of reducing agents are also known. Apart from Cu-exchanged zeolites (cf., for example, EP-A-0914866), iron-containing zeolites in particular appear to be of
10 interest for practical use.

Thus, US-A-4,571,329 claims a process for reducing NO_x in a gas comprising at least 50% of NO₂ by means of ammonia in the presence of an Fe zeolite. The ratio of
15 NH₃ to NO₂ is at least 1.3. According to the process described in this patent, NO_x-containing gases are said to be reduced by means of ammonia without formation of N₂O as by-product occurring.

20 US 5,451,387 describes a process for the selective catalytic reduction of NO_x by means of NH₃ over iron-exchanged zeolites at temperatures of about 400°C.

25 In contrast to the removal of NO_x from offgases, which has been established industrially for many years, there are only few industrial processes for eliminating N₂O. These are usually based on thermal or catalytic degradation of the N₂O. An overview of catalysts whose in-principle suitability for the degradation and
30 removal of nitrous oxide has been demonstrated, is given by Kapteijn et al. (Kapteijn F. et al., Appl. Cat. B: Environmental 9 (1966) 25-64).

35 Fe and Cu zeolite catalysts which either effect a pure decomposition of the N₂O into N₂ and O₂ (US-A-5,171,553) or catalytically reduce the N₂O with the aid of NH₃ or hydrocarbons to N₂ and H₂O or CO₂ appear to be particularly useful.

Thus, JP-A-07 060 126 describes a process for reducing N₂O by means of NH₃ in the presence of iron-containing zeolites of the pentasil type at temperatures of 450°C. The reduction in the N₂O concentration which can be 5 achieved by means of this process is 71%.

In Catal. Lett. 62 (1999) 41-44, Mauvezin et al. give an overview of the suitability of various, iron-exchanged zeolites of the MOR, MFI, BEA, FER, FAU, MAZ 10 and OFF types for this purpose. According to this reference, reduction of more than 90% of the N₂O can be achieved by addition of NH₃ at below 500°C only in the case of Fe-BEA.

15 Apart from the abovementioned processes for the separate removal of N₂O and NO_x, there are also processes for combined removal which can be carried out using a single catalyst.

20 WO-A-00/48715 discloses a process in which an NO_x- and N₂O-containing offgas is passed at temperatures of from 200 to 600°C over an iron zeolite catalyst of the beta type (= BEA type), with the offgas additionally containing NH₃ in a ratio of from 0.7 to 1.4 based on 25 the total amount of NO_x and N₂O. Here, NH₃ serves as reducing agent both for NO_x and for N₂O. Although the process operates at temperatures of less than 500°C, it suffers, like the abovementioned process, from the in-principle disadvantage that an approximately equimolar 30 amount of reducing agent (here NH₃) is required to eliminate the N₂O content.

WO-A-01/51,181 discloses a process for the removal of NO_x and N₂O, in which a process gas or offgas is passed 35 through two reaction zones containing iron-laden zeolites as catalysts. In the first reaction zone, N₂O is removed, ammonia is added to the gas mixture between the first and second reaction zones and NO_x is reduced in the second reduction zone.

It has now surprisingly been found that the effectiveness of the abovementioned process can be increased significantly when the reduction in the N₂O content to the desired degree of removal occurs not solely in the first reaction zone, but instead the reaction zone for the NO_x reduction can also be utilized for reducing the N₂O content. This has become possible since it has surprisingly been established that simultaneous NO_x reduction (e.g. by means of NH₃) and N₂O decomposition is possible when using iron-laden zeolite catalysts. The contribution of the second reaction step to the decomposition of N₂O is particularly great when the process is operated at elevated pressures, i.e. at pressures above 2 bar, preferably above 4 bar.

It is an object of the present invention to provide a simple but economical process which gives good conversions both for NO_x removal and for N₂O removal and has minimal operating and capital costs. The former includes not only the energy for setting the necessary operating temperature but also the consumption of reducing agent and energy losses due to resistances to flow in the catalyst bed (pressure drops). The capital costs are determined essentially by the required amounts of catalyst and the apparatus volumes associated therewith.

In addition, there is the problem of introducing the reducing agent which has to be mixed intimately with the gas stream to be treated in order to ensure a very high efficiency of the reducing agent (avoidance of secondary reactions and passage without reaction). The mixer necessary for this purpose should take up as little space as possible because of installation and economic considerations.

These objects are achieved by the process of the

invention and the apparatus of the invention.

The invention provides a process for reducing the content of NO_x and N_2O in gases, in particular in process gases and offgases, which comprises the measures:

- 5 a) passing the N_2O - and NO_x -containing gas over a sequence of two catalyst beds comprising one or more iron-laden zeolites,
- 10 b) adding a reducing agent for NO_x between the catalyst beds,
- c) setting a temperature of less than 500°C in the first catalyst bed and second catalyst bed,
- 15 d) setting a gas pressure of at least 2 bar in the two catalyst beds,
- e) selecting a space velocity in the first and second catalyst beds such that a reduction in the N_2O content of the gas by not more than 20 90%, based on the N_2O content at the entrance to the first catalyst bed, occurs in the first catalyst bed and that a further reduction in the N_2O content of the gas by at least 30%, based on the N_2O content at the entrance to the 25 second catalyst bed, occurs in the second catalyst bed.

In the first catalyst bed for pure N_2O decomposition, the NO_x which is still present in the gas accelerates, 30 as expected, the desired N_2O decomposition by means of an activating action as has been described for various $\text{N}_2\text{O}/\text{NO}_x$ ratios by Kögel et al. in Catal. Comm. 2 (2001) 273-6.

35 However, an appreciable decrease in the N_2O concentration by decomposition into nitrogen and oxygen can be achieved in the second catalyst bed, too. This was surprising since, firstly, the NO_x content which activates the N_2O decomposition is reduced by addition

of the reducing agent and, secondly, it was expected that the reducing agent added would be temporarily adsorbed on the catalyst surface and thus block the active sites for N₂O decomposition.

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Under the chosen process conditions, i.e. the elevated pressures and in particular a reduced NH₃/NO_x ratio, these influences obviously do not come to bear.

10 The process of the invention thus makes it possible to carry out both the decomposition of N₂O and the reduction of NO_x at a low operating temperature and economical space velocities and at the same time achieve high degrees of removal of N₂O and NO_x.

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For the purposes of the present invention, the space velocity is the volume of gas mixture (measured at 0°C and 1.014 bara) per hour divided by the volume of catalyst. The space velocity can thus be set via the 20 volume flow of the gas and/or via the amount of catalyst.

The gas laden with nitrogen oxides is usually passed over the catalyst at a space velocity of from 200 to 25 200,000 h⁻¹, preferably from 5,000 to 100,000 h⁻¹, in particular from 5,000 to 50,000 h⁻¹, based on the total catalyst volume of the two catalyst beds.

After leaving the first catalyst bed, the N₂O content 30 is, according to the process of the invention, preferably above 200 ppm, in particular above 300 ppm. A reduction of not more than 90%, preferably not more than 80%, in the N₂O content present at the beginning of the first catalyst bed occurs in the first catalyst 35 bed.

After leaving the first catalyst bed, the N₂O- and NO_x-containing gas is firstly mixed with a gaseous reducing agent, preferably with NH₃, and subsequently passed

over the catalyst at a temperature of preferably less than 450°C and at the chosen space velocity to achieve simultaneous removal of N₂O (by decomposition) and NO_x (by reduction).

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In the second catalyst bed, an additional reduction of at least 30%, preferably at least 40%, in the N₂O content present at the beginning of the second catalyst bed occurs.

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In the process of the invention, iron-containing zeolites are used in the first and second catalyst beds. The catalysts used in the respective catalyst beds can be different or can preferably be the same catalyst.

Physical separation of the catalyst beds makes it possible to set the temperature of the second catalyst bed or of the gas stream entering it by removal or 20 introduction of heat so that it is lower or higher than that of the first catalyst bed.

The temperature of the gas stream in the first catalyst bed in which only the N₂O is removed and also in the 25 second catalyst bed in which N₂O and NO_x are removed is, according to the invention, below 500°C, preferably in the range from 250 to 500°C, in particular from 300 to 450°C and very particularly preferably from 350 to 450°C. The temperature in the second catalyst bed 30 preferably corresponds to the temperature in the first catalyst bed. The temperature in the catalyst bed can advantageously be determined as the arithmetic mean of the temperature of the gas stream at the entrance to and exit from the catalyst bed.

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The choice of operating temperature is, like the space velocity selected, determined by the desired degree of removal of N₂O.

The temperature, volume flow and amount of catalyst in the first catalyst bed are preferably selected so that not more than 90%, preferably not more than 80% and very particularly preferably not more than 70%, of the 5 N₂O present at the beginning of the first catalyst bed is decomposed in the first catalyst bed.

The temperature, volume flow and amount of catalyst in the second catalyst bed are preferably selected so that 10 a further reduction in the N₂O content of the gas by at least 30%, based on the N₂O content at the entrance to the second catalyst bed, occurs in the second catalyst bed.

15 The process of the invention is carried out at an elevated pressure of at least 2 bar, preferably at least 3 bar, very particularly preferably from 4 to 25 bar. The introduction of the reducing agent between the first catalyst bed and the second catalyst bed, 20 i.e. downstream of the first and upstream of the second catalyst bed, is carried out by means of a suitable device, e.g. an appropriate pressure valve or appropriately configured nozzles.

25 In the first reaction zone, a relatively low water concentration is generally preferred, since a very high water content would make high operating temperatures (e.g. >500°C) necessary. Depending on the type of zeolite used and the time of operation, this could 30 exceed the hydrothermal stability limits of the catalyst. However, the NO_x content plays a critical role here, since this can stop deactivation by water.

35 In the case of the NO_x reduction in the second reaction zone, a high water content plays a minor role, since high degrees of removal of NO_x are achieved here even at relatively low temperatures.

The reducing agent is used in the amount required for

reduction of the NO_x . For the purposes of the present description, this is that amount of reducing agent which is necessary to reduce the NO_x present in the gas mixture either completely or to the desired final 5 concentration without appreciable reduction of N_2O taking place.

As reducing agents for the purposes of the invention, it is possible to use substances which have a high 10 activity and selectivity for the reduction of N_2O and whose selectivity and activity under the reaction conditions selected is greater than that for the possible reduction of N_2O .

15 Reducing agents which can be used for the purposes of the invention are, for example, hydrocarbons, hydrogen, carbon monoxide, ammonia or mixtures thereof, e.g. synthesis gas. Particular preference is given to ammonia or substances which liberate ammonia when they 20 are introduced, e.g. urea or ammonium carbamate.

The amount of reducing agent added must not be appreciably greater than that required for the reduction of NO_x under the reaction conditions 25 selected.

In the case of ammonia as reducing agent, use is made, depending on the desired degree to which the NO_x content is to be decreased, of up to a maximum of 1.2, 30 preferably from 1.0 to 1.2, mol of ammonia per mol of NO_x . If a relatively low degree of removal of NO_x is desired, the maximum amount of ammonia is $1.2 \times y$ mol per mol of NO_x ; y is the percentage of NO_x which is to be consumed in the reduction.

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When suitable catalysts and process conditions are chosen, the NH_3 added does not act as reducing agent for N_2O but instead selectively reduces the NO_x present in the offgas.

The process of the invention thus makes it possible to carry out the removal of N_2O and of NO_x at a lower operating temperature with a small consumption of 5 gaseous reducing agent, e.g. NH_3 , which has hitherto not been possible by means of the processes described in the prior art.

This is a particularly great advantage when large 10 amounts of N_2O are to be eliminated.

The way in which the gaseous reducing agent is introduced into the gas stream to be treated can be chosen freely for the purposes of the invention as long 15 as the introduction is upstream of the second catalyst bed. The reducing agent can be introduced, for example, in the inlet line upstream of the container for the second catalyst bed or immediately before the catalyst bed. The reducing agent can be introduced in the form 20 of a gas or else a liquid or aqueous solution which vaporizes in the gas stream to be treated.

Catalysts used according to the invention substantially comprise one or more iron-laden zeolites, preferably in 25 an amount of >50% by weight, in particular >70% by weight. Thus, for example, not only an Fe-ZSM-5 zeolite but also a further iron-containing zeolite, e.g. an iron-containing zeolite of the MFI or FER type, can be present in the catalyst used according to the 30 invention. In addition, the catalyst used according to the invention can further comprise other additives known to those skilled in the art, e.g. binders.

Catalysts used according to the invention are 35 preferably based on zeolites into which iron has been introduced by solid-state ion exchange. The commercially available ammonium zeolites (e.g. NH_4 -ZSM-5) and appropriate iron salts (e.g. $FeSO_4 \times 7 H_2O$) are usually used as starting materials for this purpose and

are intensively mixed with one another by mechanical means in a ball mill at room temperature. (Turek et al.; Appl. Catal. 184, (1999) 249-256; EP-A-0 955 080). The references are hereby expressly incorporated by 5 reference. The catalyst powders obtained are subsequently calcined in air at temperatures in the range from 400 to 600°C in a muffle furnace. After calcination, the iron-containing zeolites are intensively washed in distilled water, filtered off and 10 dried. The iron-containing zeolites obtained in this way are subsequently admixed with suitable binders and mixed and, for example, extruded to form cylindrical catalyst bodies. Suitable binders include all binders customarily used; the most widely used here are 15 aluminum silicates such as kaolin.

According to the present invention, the zeolites which can be used are laden with iron. The iron content can be up to 25%, but is preferably from 0.1 to 10%, based 20 on the mass of zeolite.

Iron-laden zeolites are preferably of the MFI, BEA, FER, MOR, FAU and/or MEL type, in particular of the ZSM-5 type.

25 In a preferred embodiment, iron-laden zeolites whose crystal structure has no pores or channels having crystallographic diameters greater than or equal to 7.0 Ångstrom are used at least in the second catalyst bed.

30 These include iron-laden zeolites of the MFI, FER and/or MEL type, in particular of the ZSM-5 type.

35 The process of the invention can also be carried out using zeolites in which part of the lattice aluminum has been isomorphously replaced by one or more elements, for example by one or more elements selected from among B, Be, Ga, Fe, Cr, V, As, Sb and Bi. The use of zeolites in which the lattice silicon is

isomorphously replaced by one or more elements, for example by one or more elements selected from among Ge, Ti, Zr and Hf, is likewise included.

5 Precise details on the configuration or structure of the zeolites used according to the invention are given in the Atlas of Zeolite Structure Types, Elsevier, 4th revised edition 1996, which is hereby expressly incorporated by reference.

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In the process of the invention, very particular preference is given to using the above-defined zeolite catalysts which have been treated with water vapor (steamed catalysts). Such treatment removes aluminum from the lattice of the zeolite, and is known per se to those skilled in the art. These hydrothermally treated zeolite catalysts surprisingly display a particularly high activity in the process of the invention.

15 20 Preference is given to using hydrothermally treated zeolite catalysts which have been laden with iron and in which the ratio of extralattice aluminum to lattice aluminum is at least 1:2, preferably from 1:2 to 20:1.

25 30 The water content of the reaction gas is preferably in the range <25% by volume, in particular in the range <15% by volume. A low water content is generally to be preferred.

35 40 In general, a relatively low water concentration is preferred, since relatively high water contents would make relatively high operating temperatures. This could, depending on the type of zeolite used and the operating time, exceed the hydrothermal stability limits of the catalyst and is thus to be matched to the particular case chosen.

The presence of CO₂ and of other deactivating constituents of the reaction gas which are known to

those skilled in the art should also be minimized if possible, since they would have an adverse effect on the N₂O removal.

5 The process of the invention also works in the presence of O₂, since the catalysts used according to the invention have appropriate selectivities which suppress reaction of the gaseous reducing agent, e.g. NH₃, with O₂ at temperatures of <500°C.

10 All these influencing factors and also the chosen throughput over the catalyst, i.e. the space velocity, are to be taken into account in choosing the appropriate operating temperature of the reaction zone.

15 The process of the invention can be used in particular in nitric acid production, for offgases from power stations or for gas turbines. Process gases and offgases which contain nitrogen oxides and from which 20 the nitrogen oxides can be removed inexpensively by means of the process disclosed here are obtained in these processes. The process of the invention is advantageously used for the tailgas from nitric acid production downstream of the absorption tower.

25 The configuration of the catalyst beds can be chosen freely for the purposes of the invention. Thus, for example, the catalyst or catalysts can be arranged in a catalyst bed through which the gas flows axially or 30 preferably radially in one or more containers.

The invention further provides an apparatus for reducing the content of NO_x and N₂O in gases, in particular in process gases and offgases, which 35 comprises:

A) two catalyst beds which are connected in series and each comprise one or more iron-laden zeolites and through which the NO_x- and N₂O-

containing gas flows,

5 B) a device for introducing a gaseous reducing agent into the stream of the NO_x- and N₂O-containing gas located between the catalyst beds, wherein

10 C) the NO_x- and N₂O-containing gas flows radially through at least one of the catalyst beds.

10 In a preferred embodiment, both catalyst beds are arranged in one container which considerably reduces the apparatus costs.

15 According to the invention, the gas to be purified flows radially through at least one catalyst bed, preferably both catalyst beds, which results in a considerably reduced pressure drop.

20 The catalyst beds through which the gas flows radially are, for example, configured in the form of hollow cylinders but can also have other shapes. The catalyst beds through which the gas flows radially can be arranged above one another or a combination of catalyst beds through which axial and radial flow occurs can be chosen. The path of the gas is prescribed by suitably 25 arranged separators between the catalyst beds so that the gas flows firstly through the first catalyst bed and then through the second catalyst bed.

30 In the case of catalyst beds through which the gas flows radially, these can also be in the form of hollow cylinders arranged concentrically within one another. In this embodiment too, it should be ensured that the path of the gas is prescribed by suitably arranged separators between the catalyst beds so that the gas 35 flows firstly through the first catalyst bed and then through the second catalyst bed.

The flow direction of the gas in the radial screen reactor can be from the inside outward or from the

outside inward.

In a preferred embodiment, there are two catalyst beds through which the gas flows radially, for example in

5 the form of two hollow cylinders, having different dimensions, with the external dimension of one catalyst bed being smaller than the internal dimension of the other catalyst bed and both catalyst beds being arranged concentrically, and with the path of the gas

10 being prescribed by suitably arranged separators between the catalyst beds so that the gas flows firstly through the first catalyst bed and then through the second catalyst bed.

15 In a further preferred embodiment of the apparatus of the invention, the gas which has passed through the first catalyst bed is passed into a mixer which is preferably located in the center of the apparatus and a feed line for reducing agent which opens into the space

20 downstream of the first catalyst bed and before or preferably into the mixer is provided, with the gas to be purified being passed through the second catalyst bed after leaving the mixer.

25 The mixer serves to distribute the reducing agent intimately in the gas stream. For the purposes of the invention, the mixer can be configured freely, for example as a static mixer with appropriate internals or as a dynamic mixer. The simplest form of a tube through

30 which flow is preferably turbulent is also possible as a mixer for the purposes of the invention.

Figures 1 to 6 show preferred embodiments of the apparatus of the invention in longitudinal section.

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Figure 1 depicts an apparatus according to the invention with gas inlet (1) and gas outlet (2). In the upper interior space closest to the gas inlet (1), the first catalyst bed is arranged in the form of a hollow

cylinder (4) and is located on a dividing wall which divides the interior of the apparatus into two halves. In addition, the upper end face of the hollow cylinder (4) is closed by a dividing wall. The gas to be 5 purified flows through the gas inlet (1) and, via the annular gap of the entrance (7) to the first catalyst bed, flows radially through the first catalyst bed into the annular gap of the exit (8) from the first catalyst bed. From there it flows into the mixer (6) at whose 10 inlet end there is the opening of an inlet line (3) for the reducing agent. Mixer (6) passes through the dividing wall and the gas then flows, via the annular gap of the entrance (9) to the second catalyst bed (5) located beneath the first catalyst bed (4), radially 15 through the second catalyst bed into the annular gap of the exit (10) from the second catalyst bed (5). From there, the purified gas leaves the apparatus via the gas outlet (2).

20 Figure 2 shows a similar embodiment as Figure 1 with the differences that the first catalyst bed (4) is located underneath the second catalyst bed (5) and that gas inlet (1) and gas outlet (2) are arranged laterally in the apparatus. The other references numerals have 25 the meanings given in the description of Figure 1.

Figure 3 depicts a further embodiment of the apparatus of the invention with gas inlet (1) and gas outlet (2). Here, the first catalyst bed (4) and the second 30 catalyst bed (5) are configured as two hollow cylinders arranged concentrically within one another. The first catalyst bed (4) is located outside a concentric dividing wall (11) which closes off the lower end face of the catalyst bed (4), the annular gaps (7) and (8) 35 and also the interior of the apparatus and the upper end face of the second catalyst bed (5). The gas to be purified enters the apparatus through the gas inlet (1) and flows radially through the first catalyst bed from the outer annular gap entrance (7) inward to the

annular gap exit (8). From there it flows into the mixer (6) at whose inlet end there is the opening of an inlet line (3) for the reducing agent. The mixer (6) opens into the interior of the second catalyst bed (5) which is closed off at the bottom by a dividing wall. The gas then flows, via the annular gap of the entrance (9) to the second catalyst bed (5), radially outward through the second catalyst bed into the annular gap of the exit (10) from the second catalyst bed (5). From there the purified gas leaves the apparatus via the gas outlet (2).

Figure 4 shows a similar embodiment as Figure 3 with the difference that the first catalyst bed (4) forms the inner hollow cylinder and the second catalyst bed (5) forms the outer hollow cylinder. The other reference numerals have the meanings given in the description of Figure 3.

Figure 5 shows an embodiment in which one catalyst bed through which the gas flows axially and one catalyst bed through which the gas flows radially are provided. The gas flows via the gas inlet (1) axially through the first catalyst bed (4) and into the mixer (6). The apparatus has a dividing wall which divides the interior of the apparatus into two halves. At the inlet end of the mixer (6) there is the opening of an inlet line (3) for the reducing agent. From the mixer (6) the gas flows into the annular gap of the entrance (9) to the second catalyst bed (5) and radially through this into the annular gap of the exit (10). From there the purified gas leaves the apparatus via the gas outlet (2).

Figure 6 shows a similar embodiment as Figure 5 with the difference that the gas flows radially through the first catalyst bed (4) and axially through the second catalyst bed (5). The other reference numerals have the meanings given in the description of Figure 3.

The process of the invention is illustrated by the following example.

5 The catalyst used was an iron-laden zeolite of the ZSM-5 type. The Fe-ZSM-5 catalyst was prepared by solid-state ion exchange starting from a commercially available zeolite in ammonium form (ALSI-PENTA, SM27). Details regarding the preparation can be taken from:
10 M. Rauscher, K. Kesore, R. Mönnig, W. Schwieger, A. Tißler, T. Turek: "Preparation of highly active Fe-ZSM-5 catalyst through solid state ion exchange for the catalytic decomposition of N₂O" in Appl. Catal. 184 (1999) 249-256.

15 The catalyst powders were calcined in air at 823 K for 6 hours, washed and dried overnight at 383 K. After addition of appropriate binders, the powders were extruded to form cylindrical catalyst bodies.

20 As apparatus for reducing the NO_x and N₂O content, use was made of two tube reactors which were connected in series and were each charged with such an amount of the above catalyst that a space velocity of 15,000 h⁻¹ based
25 on the inflowing gas stream resulted in each case. NH₃ gas was added between the two reaction zones. The operating temperature of the reaction zones was set by means of heating. The analysis of the gas streams entering and leaving the reactors was carried out by
30 means of an FTIR gas analyzer.

At inlet concentrations of 1,500 ppm of N₂O, 350 ppm of NO_x, 3,000 ppm of H₂O and 1.2% by volume of O₂ and N₂ and with intermediate addition of NH₃ at a uniform
35 operating temperature of 425°C and an operating pressure of 6.5 bar, the conversion results for N₂O, NO_x and NH₃ listed in the following table were obtained.

Table

	Inlet concentration	Outlet concentration	Conversion
N ₂ O	1,500 ppm (reactor 1)	540 ppm (reactor 1)	64%
NO _x (x=1-2)	360 ppm (reactor 2)	80 ppm (reactor 2)	78%
NH ₃	310 ppm* (reactor 2)	0 ppm (reactor 2)	100%
N ₂ O	540 ppm (reactor 2)	190 ppm (reactor 2)	65%

*' added between the first reactor and the second reactor

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- 20 -

EP0306051

A M E N D E D S H E E T S

Claims:

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1. A process for reducing the content of NO_x and N₂O in gases, in particular in process gases and offgases, which comprises the measures:
 - 5 a) passing the N₂O- and NO_x-containing gas over a sequence of two catalyst beds comprising one or more iron-laden zeolites,
 - 10 b) adding a reducing agent for NO_x between the catalyst beds,
 - c) setting a temperature of less than 500°C in the first catalyst bed and second catalyst bed,
 - 15 d) setting a gas pressure of at least 2 bar in the two catalyst beds,
 - e) selecting a space velocity in the first and second catalyst beds such that a reduction in the N₂O content of the gas by not more than 20%, based on the N₂O content at the entrance to the first catalyst bed, occurs in the first catalyst bed and an N₂O content of greater than 200 ppm is established and that a further reduction in the N₂O content of the gas by at least 30%, based on the N₂O content at the entrance to the second catalyst bed, occurs in the second catalyst bed.
2. The process as claimed in claim 1, characterized in that the same catalyst is used in the first and second catalyst beds.
3. The process as claimed in claim 1, characterized in that the iron-laden zeolite or zeolites is/are of the MFI, BEA, FER, MOR, FAU and/or MEL type.
- 35 4. The process as claimed in claim 3, characterized in that the iron-laden zeolite is of the MFI type.

5. The process as claimed in claim 1, characterized in that the zeolite is an Fe-ZSM-5.
- 5 6. The process as claimed in claim 1, characterized in that the process is carried out at a pressure in the range from 4 to 25 bar.
- 10 7. The process as claimed in claim 1, characterized in that ammonia is used as reducing agent for NO_x and is employed in an amount of from 1.0 to 1.2 mol per mol of NO_x to be removed.
- 15 8. The process as claimed in claim 1, characterized in that the NO_x- and N₂O-containing gas is passed over each of the catalyst beds at a space velocity of from 5,000 to 50,000 h⁻¹, based on the total catalyst volume of the two catalyst beds.
- 20 9. The process as claimed in claim 1, characterized in that the temperature in the first and second reaction zones is from 350 to 450°C.
- 25 10. The process as claimed in claim 1, characterized in that iron-laden zeolites which have been treated with water vapor are used in at least one catalyst bed.
- 30 11. The process as claimed in claim 1, characterized in that iron-laden zeolites in which the ratio of extralattice aluminum to lattice aluminum is at least 0.5 are used as catalysts in at least one catalyst bed.
- 35 12. The process as claimed in claim 1, characterized in that it is integrated into the process for nitric acid production.

13. The process as claimed in claim 1, characterized in that it is integrated into the process of operation of a gas turbine.

5 14. The process as claimed in claim 1, characterized in that it is integrated into the process of operation of a power station.

10 15. An apparatus for reducing the content of NO_x and N₂O in gases, in particular in process gases and offgases, which comprises:

15 A) two catalyst beds which are connected in series and each comprise one or more iron-laden zeolites and through which the NO_x- and N₂O-containing gas flows,

20 B) a device for introducing a gaseous reducing agent into the stream of the NO_x- and N₂O-containing gas located between the catalyst beds, which comprises a mixer through which the gas which has flowed through the first catalyst bed is passed and a feed line for reducing agent which opens into the space downstream of the first catalyst bed and before or into the mixer, with the gas to be purified being passed through the second catalyst bed after leaving the mixer, wherein

25 C) at least one of the catalyst beds is configured as a hollow cylinder through which the NO_x- and N₂O-containing gas flows radially.

30 16. The apparatus as claimed in claim 15, characterized in that both catalyst beds are arranged in one container.

35 17. The apparatus as claimed in claim 15, characterized in that the NO_x- and N₂O-containing gas flows radially through both catalyst beds.

18. The apparatus as claimed in claim 15, characterized in that two catalyst beds through which the gas flows radially are arranged above one another or in that a combination of catalyst beds through which the gas flows axially and radially and which are arranged above one another is present, with the path of the gas being prescribed by suitably arranged separators between the catalyst beds so that the gas flows firstly through the first catalyst bed and then through the second catalyst bed.

19. The apparatus as claimed in claim 15, characterized in that two catalyst beds through which the gas flows radially and which have different dimensions are present, with the external dimension of one catalyst bed being smaller than the internal dimension of the other catalyst bed and both catalyst beds being arranged concentrically, and with the path of the gas being prescribed by suitably arranged separators between the catalyst beds so that the gas flows firstly through the first catalyst bed and then through the second catalyst bed.

20. The apparatus as claimed in claim 15, characterized in that the gas which has passed through the first catalyst bed is passed into a mixer located in the center of the apparatus.

21. The apparatus as claimed in claim 15, characterized in that the mixer is configured as a static mixer or as a dynamic mixer, preferably in the form of a tube through which the gas flows.